# On the absence of a measurement problem in quantum computer science

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I comment on GianCarlo Ghirardi's criticism of my claim that quantum computation has no measurement problem.

In view of GianCarlo Ghirardi's remarks (arXiv:0806.0647) about my *In Praise of Measurement* (arXiv:quant-ph/0612216), I should clarify what I meant to say in that paper and in the conference lecture on which it was based. I wanted to make two points about measurement in quantum computer science. The first was that the simple and crucial role of measurement gates deserved greater emphasis:

(a) The only measurement gates ever needed are multiple copies of a single one, that acts on a single Qbit. All other processes called "measurement" can be built out of 1-Qbit measurement gates and unitary gates. The question of what qualifies as a measurement has a precise answer.

(b) Applying and reading measurement gates is an indispensable part of any computation. If gates were restricted to unitary gates, then quantum computation would be useless, since no user could acquire any numerical information.

(c) In addition to creating the output of the computation, measurement gates are the most conceptually straightforward and pedagogically economical way to get the computation underway, by, for example, enabling the user to assign to each Qbit the initial state $|0\rangle$.

My second point was that if quantum mechanics were *only* a branch of computer science that applied *only* to the operation of quantum computers, then there would be no measurement problem. This conclusion grew out of my experience teaching quantum mechanics to computer scientists for 6 years, during which no "measurement problem" ever arose in the course of innumerable discussions with students trying to learn the subject without any prior knowledge of quantum mechanics, and during which I, as teacher, never felt dissatisfied with what I was able to tell the students, as I do at various points when teaching a physics course in conventional quantum physics. For more on this see Part 3 of *Copenhagen Computation: How I Learned to Stop Worrying and Love Bohr* (arXiv:quant-ph/0305088).

Ghirardi objects to my second point, making me realize that I should have been more emphatic that the claim in my article that there is no measurement problem is limited to quantum computer science. My abstract says "I argue that within the field of quantum computer science the concept of measurement is . . . unproblematic . . . ." And in the paper

I say my subject is "the role of measurement in quantum computation." And toward the end I say that measurement "is [not] problematic in quantum computer science." Only in the last five paragraphs do I raise the question of whether "this generalizes beyond quantum computation" and make some tentative suggestions about how it might.

I should, however, have stated explicitly that I was not claiming that quantum computation provided a solution to the broader measurement problem, but only that it described a conceptual microcosm within which there was nothing problematic about measurement. I did not intend to imply that this "weakened or even cancelled" John Bell's criticisms of quantum mechanics as a satisfactory picture of the entire physical world. On the contrary, at the beginning I say "I'm not sure Bell would have found any of the remarks that follow compelling, or even suggestive." To underline my reservations about how Bell might have reacted I voice the hope that Anton Zeilinger (the honoree at the conference) might "take a more sympathetic view of it than Bell might have done." After that, aside from asserting that Bell would have enjoyed the quantum information revolution, I don't speculate on how he might have responded, mentioning him only when I note how some of his complaints about quantum foundations look in the restricted setting of quantum computer science. I brought Bell into the story because the talk was at a conference of people, most of whom were more involved in aspects of quantum information, than they were in quantum foundations. I could not assume that all (or even most) of them had heard of a "measurement problem", and could imagine no more effective way of introducing them to the issues than to refer them to and quote from Bell's brilliant and delightful essay, *Against Measurement.*

On the matter of Bell's use of "exact", I was indeed thinking only of his definition of "exact" in *Against Measurement*: "fully formulated in mathematical terms, with nothing left to the discretion of the theoretical physicist." I didn't know (or had forgotten) that, as Ghirardi points out, elsewhere Bell uses the term to mean a theory that "neither needs nor is embarrassed by an observer." But had I known this, I would have added a remark to the effect that the "user", though not always explicit in computer science, can hardly be viewed as an embarrassment to the field. (I know an information scientist at Cornell whose specialty is "The Computer-Human Interface". As far as I know, this does not embarrass her or her colleagues.) I do talk about the "user", particularly in joking about God and Einstein's mouse, but without realizing that I was touching on another aspect of Bell's notion of "exactness".

Having said this, I must acknowledge that Ghirardi correctly infers that there are matters on which we disagree. My own current view is along the lines of the Bohr quotation I give at the beginning of *In Praise of Measurement*: "In our description of nature the purpose is not to disclose the real essence of the phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience." I take this to mean that quantum states are not entities with an objective existence, or inherent properties of the systems with which they are associated, but mathematical constructs that enable us to relate some of our experiences (e.g. what we read on the display of the

measurement gates that prepare the initial state) to others (e.g. what we read when we look at the display of the final measurement gates). When we have new experiences we update our state assignments accordingly, and this is indeed a nonlinear alteration. But what is altered is an abstraction that provides a remarkably effective starting point for subsequent calculation; it is not a real essence of the phenomena.

Admittedly, for this to be a coherent position, one must take some of the manifold aspects of our experience to lie beyond the domain that physics describes. The concepts that physics has developed are incapable of capturing the taste — the indescribable flavor — of individual conscious experience. Physics has the goal of accounting for correlations among different aspects of that (irreducible) experience (which is all we could possibly need from it). Quantum computer science illustrates this strikingly and unproblematically through a user, whose personal experience makes possible the initial input and acknowledges the final output.

If there is a tricky conceptual issue within quantum computer science it is not a measurement problem, but a unitary-evolution problem. Measurements are a conceptually straightforward part of how you initiate and conclude the computation. But the state that evolves unitarily after the initial and before the final measurements is more subtle. Students (and many contemporary physicists, including, I believe, Ghirardi) want to regard the state as a real essence of the phenomena — an objective property of the Qbits (as we are used to regarding the state of classical Cbits) — even though there is no way to determine what the state is, given only the Qbits, and even though that view leads unambiguously to unmediated (spooky) action at a distance. In teaching quantum computation to computer science students (and in my book *Quantum Computer Science: An Introduction*) I stress that the state and the unitary transformations it is subject to are mathematical abstractions that enable one to compute from a knowledge of the readings of the initial measurement gates and the components of the circuit that follows, the probabilities of the readings of the final measurement gates. Mathematical abstractions do not require stochastic "hits" originating in unknown physical processes (or interactions with gravitons) to be reset; they are reset by us, when we acquire more information and want to calculate what we can expect to experience next.

So I do maintain that there is no measurement problem within quantum computer science. And I very much wish that John Bell were still among us to object.